

Are Procyclical Productivity Fluctuations a Figment of Measurement Error?

INTRODUCTION

Multifactor productivity (MFP), or “Solow’s residual,” exhibits pronounced procyclical fluctuations in official data for the United States, Japan, and most other countries. These procyclical fluctuations have come to play a central role in recent macroeconomic debates. They provide the *modus vivendum* of the real business cycle (RBC) model, as well as the basis for Robert Hall’s (1986, 1988) interpretation that the procyclicality of MFP demonstrates the existence of market power and/or increasing returns. They are also cited to support recent search models which demonstrate increasing returns in the form of “thick market externalities.”¹

Scattered through the literature of the past three decades are suggestions that the mismeasurement of output, capital input, or of labor input, might contribute to the observed procyclicality of MFP. However, each of these three mismeasurement sources was examined singly by different authors. This essay is the first to study the potential for all three sources of mismeasurement, interacting together, fully to explain the procyclicality of MFP.

The essay begins with a theoretical analysis that places the potential sources of mismeasurement in an explicit technological context. Part of the observed procyclicality of MFP may indeed be due to mismeasurement, but part may represent the overhead nature of some portion of both labor and capital, due to technological indivisibilities. We set out a model that allows separate roles for several cyclical phenomena that have often been confused in the literature

¹ This phrase is Hall’s; the theoretical literature on this type of search model begins with Diamond (1982).

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on procyclical MFP, including labor hoarding, variable work effort, variable capital utilization, overhead labor, and overhead capital.

While measured output, labor input, and capacity utilization can be observed, several concepts in the theoretical analysis are unobservable, for example, the share of overhead labor and capital and the elasticity of unobserved labor effort to observed labor input. The empirical analysis combines data on observables with alternative assumed values of unobservables to provide a menu of plausible parameters that eliminate procyclical technology shocks as an explanation of the procyclicality of observed MFP.

The Rediscovery of Procyclical MFP

More than three decades ago Hultgren (1960) called attention to the procyclicality of labor productivity and the difficulty of reconciling its procyclical behavior with the neoclassical theory of production. His observation spawned substantial research in the 1960s, including suggestions that mismeasurement of labor or capital might help to explain the paradox.

Since the late 1960s macroeconomic debates in the United States have centered on the competing interpretations of the new classical and new Keynesian macroeconomics. The initial new classical model developed in the early 1970s by Robert E. Lucas, Jr., combined market-clearing, imperfect information, and rational expectations. After much testing, it was eventually rejected in the late 1970s for failing to explain why business cycles lasted on average four years while information delays lasted only a few weeks. It was soon replaced by a second new classical approach, the Real Business Cycle (RBC) model, which was also based on continuous market clearing and competitive equilibrium, but now generated the business cycle through serially correlated procyclical technology shocks. For the RBC model to maintain its validity, the observed procyclicality of MFP must be driven by a technological shift parameter, and not by such phenomena as mismeasurement or overhead labor.²

A second approach is embodied in the recent work of Robert Hall (1986, 1988). In Hall's interpretation, the procyclicality of MFP demonstrates market power and/or increasing returns. Since microeconomists have long known that market power existed, their interest in Hall's finding is primarily methodological, since his evidence for market power is based on macro time-series data rather than the usual micro approach grounded in the analysis of cross-sections of observations on individual firms.³

Both the RBC and market power interpretations of procyclical MFP fluctuations have been resisted by some critics. The RBC model has been subject to

² Eichenbaum (1991) develops a hybrid model that incorporates labor hoarding into the RBC model and shows that this reduces the ability of technology shocks to account for aggregate productivity fluctuations by 30 to 60 percent, depending on the sample period.

³ Domowitz, Hubbard, and Peterson (1988) use Hall's technique to explore the sensitivity of his results to an alternative set of time series data at the firm level.

many criticisms, including skepticism of the fast-paced technological regress and revival required for technology shocks to explain the time path of productivity in typical U.S. postwar recessions or the huge collapse of technology required to explain the Great Depression.⁴ Objecting to Hall's market-power interpretation, Rotemberg and Summers (1990) have argued that cyclical MFP fluctuations reflect labor hoarding and price stickiness, rather than providing any evidence in support of market power. In turn, Hall's responses to his critics (1990a, 1990b) dismiss all but two (market power, increasing returns) of eight possible "explanations" of procyclical MFP and deny four "nonexplanations" that include labor hoarding.

Previous Research on Procyclical Productivity

In the mid-1960s the cyclical behavior of productivity arose in three contexts: the paradox of short-run increasing returns to labor, Okun's law, and the labor market of the canonical Keynesian macro model.

The paradox of "SRIRL" (short-run increasing returns to labor) was simple and was recognized almost immediately after Solow's (1957) pathbreaking paper by Hultgren (1960), Oi (1962), Solow himself (1964), and others. Take a constant returns Cobb-Douglas production function with an elasticity of measured output (x) to measured labor input (h) of, say, 0.75, and vary labor while holding capital fixed; output should move less than in proportion to labor, so the average product of labor should move countercyclically. But in the data labor's average product (x/h) moves procyclically, exhibiting increasing returns, with a SRIRL parameter ($\beta = \Delta x/\Delta h$) greater than unity rather than the diminishing returns built into the production function.

The second context was Okun's law, which dates back to Okun's famous (1962) paper on potential output. His law is just a stylized fact, that the unemployment rate varies only 1 percentage point for each 3 percentage point change in detrended output; the other two percentage points are accounted for by procyclical variations in the labor force participation rate, hours per employee, and the average product of labor.⁵ The stylized fact of Okun's law provided an explicit measurement of the extent of short-run increasing returns to labor. In

⁴ Bernanke and Parkinson (1990) show that the pattern of procyclical productivity across industries in the interwar period was similar to that in the postwar. They argue that "under the presumption that the Depression was not caused by large negative technological shocks, these findings are inconsistent with the technological shocks hypothesis and provide evidence against real business cycle theory in general." Plosser (1989) provides a sympathetic exposition of the RBC model and numerous references to the original scholarly literature, while Mankiw (1989) provides a wide-ranging critique.

⁵ We have known for a long time that, allowing for lags in the adjustment of labor to output, the elasticity of unemployment to output is closer to 0.45 than 0.33, as shown in Gordon (1984), a paper that relates Okun's Law to the set of identities that link cyclical fluctuations in the unemployment rate to cyclical fluctuations in output, productivity, labor force participation, hours, and other variables. We return below to the estimation of β .

Okun's version, the response of the unemployment rate to changes in measured labor hours was one half, the other half taking the form of changes in participation and hours per employee. The elasticity of measured hours to output ($\Delta h/\Delta x$) was $2/3$, with the remainder taking the form of changes in labor's average product. Thus the SRIRL parameter ($\beta = \Delta x/\Delta h$) was 1.5.

The third context was the standard Keynesian macro model of the day, which was internally inconsistent by mixing the multiplier, based on the failure of product markets to clear, with continuous market clearing in the labor market. Firms were described as sliding back and forth along a labor demand curve that sloped down because of diminishing returns, requiring the average product of labor to move countercyclically. The fact of SRIRL conflicted with the labor-market assumptions of the Keynesian model and called attention to its internal inconsistency.

So much for the old puzzles. The old solutions were in place and widely accepted by the end of the 1960s. The way out of the internal contradiction of the Keynesian model was developed in two pieces by Don Patinkin (1965, Chapter 13) and Robert Clower (1965), and then put together by Robert Barro and Herschel Grossman (1971). No longer did the Keynesian model mix a nonmarket clearing multiplier in the product market with equilibrium in the labor market; instead the Barro-Grossman framework was based on consistent non-Walrasian framework, with spillovers and rationing in all markets.

The Barro-Grossman model straightened out the theoretical contradiction of the Keynesian model but shed no light on the paradox of short-run increasing returns. One solution proposed by Fair (1969) was that hours actually worked differ from hours paid for, and so short-run increasing returns are exaggerated when labor's average product is measured by hours paid for. Thus Fair's solution was that the paradox was explained by mismeasurement of labor. The second line of work goes back at least to Zvi Griliches (1964) and argues that standard data on the capital stock mismeasure the true input of capital services in the production function, and that the correct measure is the capital stock times the utilization rate of capital.⁶ If output fluctuates more than labor input because the input of capital services also fluctuates more than labor input, much of the SRIRL paradox disappears.⁷

⁶ Griliches (1964) developed several ideas that were then applied to the estimate of MFP growth in Jorgenson and Griliches (1967), including the adjustment of capital input for varying utilization, based on data on the power consumption of electric motors. More recently, Griliches (with Abbott and Hausman, 1988 and also in Eden-Griliches, 1991) has criticized Hall's research on several grounds, one of which is a failure to allow for variable capacity utilization. A research team which early recognized the importance of capital utilization in creating a bias in the estimated SRIRL parameter was Ireland and Smyth (1970), who latter in Ireland, Briscoe, and Smyth (1973) used electricity consumption data to correct the bias. Other references on utilization include Prucha and Nadiri (1991).

⁷ In view of this background, Hall's recent work misleads the reader that a new topic has been discovered. He writes (1990b) that "users . . . have always been aware that the Solow residual . . . fluctuates markedly, but until recently the higher-frequency movements were considered irrelevant noise," thus ignoring all of the 1960s literature on SRIRL, Okun's law, and mismeasurement. In fact, the emphasis on mismeasurement in this paper was anticipated by Evsey

The core of this paper shows how measurement errors in output, labor, and capital, can interact to provide a full explanation for the procyclicality of conventionally measured changes in MFP. It also shows why mismeasurement of labor is observationally equivalent to the existence of an overhead component of labor and perforce of capital. Empirical evidence is provided to pin down the values of the key theoretical parameters. The implications of our analysis are significant: plausible parameters of measurement error and/or overhead labor can extinguish the procyclical technology shocks that provide the *modus vivendum* of RBC models and Hall's market power interpretation, as well as the new generation of search models characterized by productivity-boosting "thick markets" in economic expansions.

8.1 THE ALGEBRA OF MISMEASUREMENT AND OVERHEAD FACTOR INPUTS

The standard approach to production theory in macroeconomics is to write down an equation like:

$$Q_t = Z_t F(N_t, K_t); \quad F_N > 0, F_{NN} < 0, F_K > 0, F_{KK} < 0. \quad (1)$$

Here Q_t is output, N_t and K_t are labor and capital input, and Z_t is a technology shift factor (i.e., Hicks-neutral technical change). Equation (1) is assumed to hold equally in the short and long run.

To adopt the notation used in the rest of this paper, lower-case letters represent logs; Δq , Δz , Δn , and Δk are log first differences of the variables in (1); hereafter we drop the t subscripts. When joined with the assumptions of constant returns and competitive factor pricing, (1) implies that the standard technique for calculating MFP (or Solow's residual, Δm) accurately measures the technological shift term:

$$\Delta m = \Delta q - \alpha \Delta n - (1 - \alpha) \Delta k = \Delta z. \quad (2)$$

where α is labor's income share.

Production in the Short Run

However fruitful may be equation (1) in describing the long-run evolution of output and inputs, its widespread use to describe the short-run production process is contradicted by both macroeconomic and microeconomic evidence. At the macroeconomic level, if the aggregate price level is sticky, then nominal aggregate demand shocks automatically become real aggregate demand shocks.⁸ Firms are no longer price takers and quantity setters, as assumed by

Domar in a remark delivered to both Hall and myself in our first MIT graduate macroeconomics class: "changes in the utilization of capital and of labor explain cyclical variations in total factor productivity" (class notes, October 26, 1964).

⁸ In its assumption of price stickiness, this analysis shares the same starting place as Rotemberg-Summers (1990). But we rely on price stickiness only to support the assumption that firms

(1), but rather are price setters and quantity takers. Having set prices, their remaining decisions are described by input demand equations for labor and capital. If input demand exhibits an elasticity to these exogenous changes in output of less than unity, measured MFP will vary procyclically even in the absence of technology shocks.

In microeconomic analysis we find a consensus going back more than two decades that the usual economic approach to production, based on the notion of homogeneous, divisible, and highly substitutable factor inputs, does not apply in most of the economy, including manufacturing, communication, transportation, and utilities. Instead, the dominant feature of the production process is heterogeneous capital that incorporates the most efficient technology available at the date of its construction but, once built, embodies fixed technical characteristics that impose tight constraints on the feasible set of input-output combinations. In the language of the 1960s, capital is putty-clay. The firm's choices are decomposed between "ex ante" investment decisions and "ex post" operating decisions, the latter involving the choice of variable inputs needed to produce desired output with existing equipment.⁹

Thus microeconomic production theory conflicts with the maintained assumption in the RBC literature and Hall's research that perfect substitution among inputs applies in the shortest run.¹⁰ For instance, Hall claims (1990b) that "as long as capital has no pure user cost, it is reasonable to assume that all capital available is in use," that is, utilization is always 100 percent. Yet this prediction is contradicted by data published by regulatory agencies for airlines, utilities, and other owners of capital equipment; the utilization of specific capital equipment types (for example, Boeing 737-300s) is highly variable over the days of the week, seasons of the year, and phases of the business cycle, simply because labor and capital are not substitutable once the labor requirements of capital equipment are "designed in."

Mismeasurement Parameters

Since our topic is the nature of fluctuations of MFP over the business cycle, we need to separate short-run (cyclical) variation from long-run trends. The subsequent empirical analysis employs several methods of detrending, including one or two log-linear trends, piecewise linear trends that allow a separate trend for

are quantity takers and make input demand decisions. Rotemberg and Summers go further and use the assumption of price stickiness to argue that price (P) is typically above marginal cost ($W \Delta N / \Delta Q$) in recessions. This requires the auxiliary assumption that the wage rate is as sticky as the price level, so that there is no cyclicity in W/P ; only on this condition is a statement that P/MC is procyclical equivalent to the statement that labor productivity ($\Delta Q / \Delta N$) is procyclical.

⁹ The distinction between the ex ante and ex post production decision is incorporated formally in almost all econometric work on the electric utility industry spanning the last three decades. See especially Wills (1978) and the survey paper by Cowing-Smith (1978).

¹⁰ For instance, Braun and Evans (1991a, 1991b) attempt to apply the neoclassical growth model with fully substitutable inputs at the seasonal frequency.

each business cycle, and the Hodrick-Prescott filter. In this section we interpret all log first differences, for example, Δq , as the first difference in the log ratio of a variable to its trend. Our analysis assumes that the technological shift term, Z_t in (1), changes only at trend frequencies but exhibits no cyclical variation. Our task is to examine the extent of mismeasurement and/or overhead factor inputs required to make the observed procyclical variations of MFP compatible with the maintained assumption of no technological shifts at the cyclical frequency.¹¹

Labor and capital input are treated symmetrically. We allow for overhead components of both labor and capital input, and for mismeasurement of each. Measured capital input (Δj) is interpreted as the capacity of the capital stock in place to produce output, for example, available seat miles flown by the airline industry or electric generating capacity in megawatts times the number of hours per year.¹² Actual capital input (Δk) is divided into the measured (Δj) change in capacity and the unmeasured change in capacity utilization (Δu):

$$\Delta k \equiv \Delta j + \Delta u. \quad (3)$$

Similarly, changes in true labor input (Δn) are divided into a measured component (Δh) and a component (Δf) representing unmeasured changes in work effort:

$$\Delta n \equiv \Delta h + \Delta f. \quad (4)$$

Now we need to parameterize the measured and unmeasured components of input fluctuations. For labor, we denote by e^N the “labor mismeasurement” parameter, that is, the fraction of true fluctuations in labor input taking the form of unmeasured changes in labor input:

$$\Delta f = e^N \Delta n; \quad \Delta h = (1 - e^N) \Delta n; \quad 0 \leq e^N \leq 1. \quad (5)$$

Similarly, we denote by e^K the “capital mismeasurement” parameter, that is, the fraction of true fluctuations in capital input taking the form of unmeasured changes in capital utilization:

$$\Delta u = e^K \Delta k; \quad \Delta j = (1 - e^K) \Delta k; \quad 0 \leq e^K \leq 1. \quad (6)$$

¹¹ Evans (1991) shows that between one quarter and one half of the variance of Solow’s residual can be explained by explicit demand variables, including money, interest rates, and government spending. This does not rule out our presumption that the rest of the variance can be explained by demand variables that Evans does not include, such as inventory cycles, fixed investment cycles, and exogenous changes in net exports.

¹² In the airline example, there is a distinction between the capacity of the measured gross capital stock (all aircraft which are on the books and have not been sold or otherwise retired) and the capacity actually flown, that is, available seat miles. The capacity of the gross capital stock shows little if any procyclical movement, while there are procyclical movements in capacity actually flown, since hours flown per plane vary with the cycle (and the seasons). This distinction between the two concepts of measured capital is eliminated to simplify the analysis; maintaining this distinction would add notational clutter without changing any of the results. The distinction between capacity and capital utilization is made by Hilton (1970).

For completeness we add the possibility of mismeasured output fluctuations when some labor effort in recessions is devoted to maintenance, training, and building new facilities, and when these forms of investment are deferred in booms. Such investment-related activities in recessions imply that true output fluctuations (Δq) are smaller in amplitude than measured output fluctuations (Δx):

$$\Delta q = (1 - e^Q)\Delta x, \quad 0 < e^Q < 1. \quad (7)$$

The parameter e^Q represents the ratio of unmeasured investment activities to measured output, and we will investigate the difference made when $e^Q = 0$, or instead e^Q is set at a small fraction like 0.05 or 0.10.

Overhead Labor and Capital

In every industry labor input is divided between a variable portion that changes in response to changes in output and a quasi-fixed portion required to run and maintain the capital stock, often called “overhead labor.” For instance, each type of commercial aircraft has a cockpit constructed to require either two or three pilots, independently of how many seats are filled. Pilot requirements are fixed once capacity is determined, while the number of flight attendants, gate agents, baggage handlers, etc., varies with output.¹³ Similarly, each railroad locomotive and freight truck has a technical requirement for one or more drivers, while loading personnel vary with the amount of freight actually carried. Assuming that all cyclical movements of labor input can be classified as fully variable or fully fixed, and denoting by v^N the fraction of variable labor, we have:

$$\Delta n = v^N \Delta q + (1 - v^N)\Delta j; \quad 0 \leq v^N \leq 1. \quad (8)$$

Available data on capacity utilization assume that all of true capital input is variable. However, if there is some overhead labor, there must be some overhead capital as well. Following Rotemberg-Summers (1990), who treat capital input for airlines as seats occupied, the seats occupied by passengers represent variable capital input, while the seats occupied by pilots, schedulers, lawyers, and executives represent fixed capital input. Thus over the cycle true capital input responds partly to output and partly to capacity:

$$\Delta k = v^K \Delta q + (1 - v^K)\Delta j; \quad 0 \leq v^K \leq 1. \quad (9)$$

Hall (1990b) refers to the variations of true capital relative to true labor input as the “capital-labor complementarity” parameter and assumes that this parameter is unity. However, the above analysis implies that this parameter (σ) is:

$$\sigma = \frac{\Delta k}{\Delta n} = \frac{v^K}{e^K v^N + (1 - e^K)v^K} \quad (10)$$

¹³ Williams (1992) has collected labor requirement functions for major categories of airline employment; baggage handlers represent fully variable labor, pilots fully fixed, while flight attendants are an intermediate category with a minimum number required for each aircraft type regardless of passengers, but the number varies above the minimum as a linear function of extra passengers.

In the simple case in which capacity does not vary over the business cycle ($e^K = 1$, implying that $\Delta j = 0$) then (10) reduces to $\sigma = v^K/v^N$, that is, the share of variable capital to the share of variable labor. There is no reason for these two shares to be the same, and hence for σ to equal unity. For instance, low-paid assembly-line workers (variable labor) might work with expensive machines like power cranes and forming presses (variable capital), while high-paid lawyers and executives (overhead labor) might work with relatively cheap capital (desks and notepads). In this example, the share of variable capital is higher than that of variable labor, implying that $\sigma > 1$.

Implications for the Measured Procyclicality of MFP

Now we can take this model in which by assumption there are no cyclical technology shocks ($\Delta z = 0$) and show the conditions required for conventionally measured MFP to be procyclical. The usual methods compute MFP (Δm) by subtracting from measured output (Δx) the change in measured inputs weighted by labor's share:

$$\begin{aligned} \Delta m &= \Delta x - \alpha \Delta h - (1 - \alpha) \Delta j \\ &= \Delta q \left[\frac{1}{1 - e^Q} - \alpha v^N (1 - e^N) \right. \\ &\quad \left. - \frac{v^K (1 - e^K) \{1 - \alpha [v^N + (1 - v^N) e^N]\}}{e^K + v^K (1 - e^K)} \right]. \end{aligned} \quad (11)$$

If there were no mismeasurement ($e^Q = e^N = e^K = 0$) and if measured labor and capital were entirely variable ($v^K = v^N = 1$), then measured output and both measured inputs would exhibit the same variability as true output ($\Delta x = \Delta h = \Delta j = \Delta q$), and clearly there would be no cyclicity to measured MFP growth ($\Delta m = 0$).

The complexity of the second line of equation (11) arises from interaction effects among capital and labor mismeasurement, and capital and labor fixity. Some intuition is provided in Table 8.1, which calculates the elasticity of measured MFP growth to true output growth ($\Delta m/\Delta q$) for each type of measurement and fixity taken one at a time. There are two columns in the table, the first corresponding to the case of no capital mismeasurement and the second to the case of complete mismeasurement. The second column of complete capital mismeasurement is of particular interest, because conventional measures of the capital stock are computed from perpetual inventories (cumulations of past investment) that by design allow for no cyclical variability of capital input. If there is no capital fixity, then complete capital mismeasurement means that true capital input varies in proportion to true output, and all of this variation takes the form of changes in the utilization of the capital stock ($\Delta k = \Delta u = \Delta q$).

Line 1 of the table shows in the first column that with no mismeasurement or input fixity, the measured MFP elasticity would be zero in a world without technological shocks. But with complete capital mismeasurement the elasticity would be substantial, equal to capital's share ($1 - \alpha$). Line 2 shows that output

Table 8.1. *Measured Elasticity of MFP to True Cyclical Changes in Output for Specified Parameters of Mismeasurement and of Input Fixity*

Deviation from Perfect Measurement and from Complete Input Variability ($e^Q = e^N = 0; v^N = v^K = 1$)	Measured MFP Elasticity ($\Delta m / \Delta q$)			
	Case when no Capital Mismeasurement ($e^K = 0$)		Case when Complete Capital Mismeasurement ($e^K = 1$)	
	Formula	Example	Formula	Example
1. None	0	0.00	$1 - \alpha$	0.25
2. Output Mismeasurement ($e^Q \neq 0$; example $e^Q = 0.1$)	$\frac{e^Q}{1 - e^Q}$	0.11	$\frac{1 - \alpha(1 - e^Q)}{1 - e^Q}$	0.36
3. Labor Mismeasurement ($e^N \neq 0$; example $e^N = 0.1$)	αe^N	0.08	$1 - \alpha(1 - e^N)$	0.33
4. Labor Partly Fixed ($v^N \neq 1$; example $v^N = 0.75$)	0	0.00	$1 - \alpha v^N$	0.44
5. Capital Partly Fixed ($v^K \neq 1$; example $v^K = 0.75$)	0	0.00	$1 - \alpha$	0.25

Notes. 1. All examples assume $\alpha = 0.75$.

2. When all inputs are variable and only capital is mismeasured, the elasticity of MFP is $e^K(1 - \alpha)$.

mismeasurement adds to line 1 an additional component of elasticity equal to the ratio of mismeasured to measured output variation ($e^Q / (1 - e^Q)$). Labor mismeasurement adds a component equal to the mismeasurement fraction times labor's share.

Lines 4 and 5 of the table show that labor and capital fixity do not matter if capital is properly measured. Our concept of fixity (equations 8 and 9 above) involves a dependence of true labor or capital input on the measured capital stock, i.e., capacity. If this is measured correctly, then the true capital stock must vary in proportion to output.¹⁴ Stated another way, if measured capacity varies in proportion to true capital input, the concept of fixity is meaningless. However, with complete capital mismeasurement in the second column of Table 8.1, labor fixity substantially boosts the measured MFP elasticity (by reducing the amplitude of cyclical movements in labor input). Capital fixity does not matter with complete capital mismeasurement, since measured capital is completely fixed by definition ($\Delta j = 0$).

Parameter Tradeoffs

We can narrow the range of plausible parameters if we reverse the question and ask, given what we know about the procyclicality of measured productivity, which combinations of parameters are consistent with the facts? Here we focus not on measured MFP but on the measured cyclicity of average labor

¹⁴ Since perfect measurement means that $\Delta j = \Delta k$, then (9) implies that $\Delta k = \Delta q$.

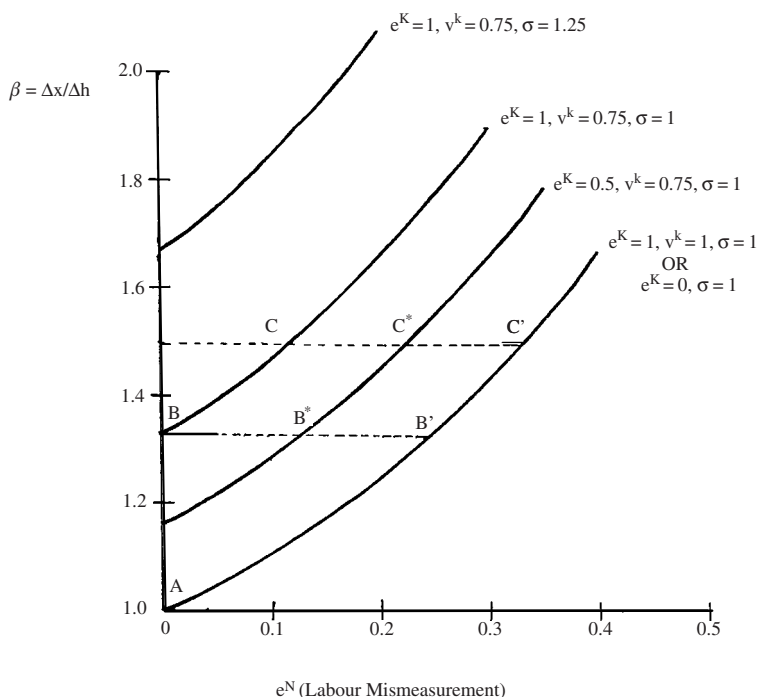


Figure 8.1. Mismeasurement Tradeoffs

productivity ($\beta = \Delta x / \Delta h$, the measured “SRIRL” parameter), simply because the size of β is a widely recognized stylized fact, about 1.5 in Okun’s original analysis and between 1.2 and 1.33 in our subsequent empirical examination.

To compute the value of β implied by our model, we can state both Δx and Δh in terms of Δq and then use equations (3) through (10) above to solve for the ratio $\Delta x / \Delta h$, in which the Δq term drops out:

$$\beta = \frac{\sigma[e^K + v^K(1 - e^K)]}{v^K(1 - e^Q)(1 - e^N)}. \quad (12)$$

With no mismeasurement and no input fixity, equation (12) reduces to $\beta = 1$. Figure 8.1 exhibits the interaction among alternative parameter values by plotting β against the labor mismeasurement parameter (e^N) for plausible combinations of the other parameters. We focus on the required amount of labor mismeasurement, simply because the existing literature provides little evidence on the quantitative magnitude of the deviation between measured labor input and true labor input, that is, on the importance of cyclical fluctuations in “labor effort.” Each of the schedules assumes that output is perfectly measured; subsequently we return to the question of output mismeasurement.

The lowest curve plots equation (12) on the assumptions of strict capital-labor complementarity ($\sigma = 1$), and either (a) perfect capital measurement (in which case capital fixity is irrelevant) or (b) complete capital mismeasurement

and fully variable capital ($v^K = 1$). This case requires large amounts of labor mismeasurement in order to explain Okun's β value of 1.5 (this requires $e^N = 0.33$ at point C') or the more empirically relevant value of 1.33 (this requires $e^N = 0.25$ at point B').

However, with the same capital-labor complementarity parameter and the fraction of variable inputs reduced from 1.0 to 0.75 ($v^K = v^N = 0.75$), Okun's β value can be explained with relatively little labor mismeasurement ($e^N = 0.11$ at point C), and the empirically relevant value of β can be explained with no labor mismeasurement at all (shown at point B). With slightly more variability in capital than in labor, for instance $\sigma = 1.25$, we obtain the highest curve, showing that empirical estimates of β can be explained without any reliance on labor or output mismeasurement. The curve going through points B^* and C^* shows that with 0.75 variable inputs, a reduction in capital mismeasurement from 1.0 to 0.5 raises the amount of labor mismeasurement that is required to explain the facts, as contrasted to points B and C .

The amount of required labor and capital mismeasurement is even less than shown in Figure 8.1 if there is any output mismeasurement, since this shifts each curve upward by $e^Q/(1 - e^Q)$. If we take e^Q to be 0.1, as suggested by Hall (1990) from the work of Fay and Medoff (1985), then this (along with the assumption that $\sigma = 1$) means that the empirical value of $\beta = 1.33$ can be explained with any combination of factor fixity and labor mismeasurement adding up to 0.165, for instance zero labor mismeasurement and 0.165 of labor and capital fixed, or completely variable labor and capital with labor mismeasurement of 0.165.¹⁵ It is in this sense that we subsequently refer to labor fixity and labor mismeasurement as "observationally equivalent" (note that the fixity and mismeasurement parameters appear multiplied together in equation 11).

Hall's Defense Against the Mismeasurement Argument

As we have seen, plausible mismeasurement parameters imply that observed productivity movements can be explained without any reliance on technological shocks, market power, or increasing returns, and what Hall calls "invariance" is upheld. How then does Hall (1990a, 1990b) dismiss the obvious force of the mismeasurement argument? His case depends both on exaggerating the size of β that needs to be explained, and also by treating each type of mismeasurement *ad seriatim* rather than jointly, thus ignoring interaction effects.

¹⁵ The Fay-Medoff results for all respondents (1985, Table 2, p. 647) indicate that in the "most recently completed cyclical downturn" shipments fell by 30 percent, while 3 percent of "normal hours" were assigned to "worthwhile other work," implying $e^Q = 3/30 = 0.1$. A possible qualification is that the Fay-Medoff survey applies only to manufacturing. Nevertheless, there are many service industries where employees may have an opportunity to work in investment-type activities during downturns, including deferred maintenance by workers in transportation, communication, and utilities, sales calls by brokers, and store refurbishment in retail trade. Fair (1985) shows that the Fay-Medoff results are consistent with an update of his earlier work (1969).

Hall examines capital mismeasurement on the assumption of no mismeasurement of labor or output. He claims that capital utilization would have to exhibit an elasticity of 5 to true labor input to be the entire explanation of procyclical MFP fluctuations, a number far above his favored elasticity of unity. His method of derivation implies that β has to be 2, which would require an Okun's law response of 4-to-1, rather than Okun's 3-to-1 or the empirical value around 2.5-to-1. And his method involves the nonsensical implicit assumption that capital utilization exhibits cyclical fluctuations 2.5 times as great as those of output itself.¹⁶ In our model the only way capital can vary five times as much as labor input is if all capital is variable while only 20 percent of labor is variable, but this requires a β of 5.

Turning now to Hall's dismissal of errors in measurement of labor, we have to deal both with facts and theories. Hall's discussion is carried out on the assumption that there is no mismeasurement of capital or output, and, as indicated in the last paragraph, that $\beta = 2$. In our analysis of Figure 8.1 these assumptions require that the labor mismeasurement parameter (e^N) must be 0.5 to eliminate cyclical fluctuations in Solow's residual. Yet Hall's dismissal of labor mismeasurement is implicitly based on a much more extreme value of e^N than implied by our analysis or by his other assumptions. He states that unmeasured work effort must have been "10 percent above normal for three successive years" in the mid 1960s to explain all of the procyclical fluctuation in Solow's residual (1990b, p. 24). But this number is too high by a factor of 2.5. Output peaked at 6 percent above normal in the mid-1960s, and measured labor input peaked at 4 percent above normal, half consisting of unemployment 2 percent below normal and half of the usual participation and hours effects. So, with a e^N parameter of 0.5, unmeasured work effort would have been only 4 percent above normal, not 10 percent. And, with the plausible combination of parameters at point C in Figure 8.1, work effort would only have been 0.44 percent above normal.

Hall's discussion of labor mismeasurement cites one additional piece of evidence on work effort. Fay and Medoff (1985) asked their manufacturing plant managers whether the work effort of blue-collar workers increased or decreased in a recession. The answers came out almost in a dead heat, with a slight balance for a countercyclical movement in effort.¹⁷ However, the needed estimate of the labor mismeasurement parameter (e^N) cannot be obtained from

¹⁶ Hall's method is to ask what value of $n = \Delta u / \Delta h$ would be necessary to imply

$$\Delta m = 0 = \Delta x - \alpha \Delta h - (1 - \alpha) \Delta u = \Delta h [\beta - \alpha - (1 - \alpha)^n].$$

With a labor's share (α) of 0.75, as we have assumed, Hall's stated value of $n = 5$ requires $\beta = 2$. But it also requires that with $\Delta x / \Delta h = 2$ and $\Delta u / \Delta h = 5$ we must have $\Delta u / \Delta x = 2.5$.

¹⁷ Fay-Medoff (1985, p. 648, footnote 30) report that there was no difference in effort in the subset of their plants that hoarded labor, i.e., maintain more workers in a recession than was technically necessary. For this subset, the tally was 34 respondents reported more effort in the recession, 35 less effort, and 45 no difference. For plants that did not hoard labor, the score was 23 more, 14 less, and 17 no difference. The overall tally indicates 34 percent more, 29 percent less, and 37 percent no difference, which is not a difference significant enough to make a case either way.

survey evidence of “effort,” which in a questionnaire may be viewed by worker respondents as synonymous with personal worth and by employer respondents as indicating more about cooperativeness and morale than an actual count of hand motions per hour. Flight attendants on planes are paid the same, but work less hard, when planes are empty. Operators at electricity generating stations are paid the same, but work less hard, when the generating unit cycles down periodically in response to slack demand. Cashiers, baggers, and stockers in supermarkets work less hard when lines are short or empty than when lines are long. In none of these situations do employees feel less worthy nor do employers sense a lack of cooperation (in fact people may seem to be “trying harder”). Consequently, it will require new and better research to reveal from surveys the counterpart of the theoretical concept of work effort.

Dynamics

The previous theoretical analysis assumes that all cyclical fluctuations occur simultaneously. It thus ignores dynamics, and in particular the lagged adjustment of labor input to changes in output. Lagged labor adjustment was a phenomenon known long before the development of sophisticated econometric tools for the analysis of time-series dynamics or even before Hultgren’s discovery of the SRIRL puzzle. For instance, Burns and Mitchell recognized that employment lagged output, and the Commerce Department has long classified unemployment as among its set of lagging indicators.

As we shall learn in the empirical section, once a low frequency trend is established, the procyclicality of productivity occurs at two higher frequencies. At the highest frequency labor input lags behind changes in output, with an adjustment speed of about three quarters. After this initial adjustment is completed, there is a remaining procyclical component due to the fact that the full adjustment of labor over the first three quarters occurs with an elasticity to output that is less than unity. This remaining component of procyclical productivity occurs at the business cycle frequency. Henceforth, we will refer to the high-frequency component of procyclical productivity (neglected in the above analysis) as due to “costly adjustment,” a separate source of procyclicality from the components that occur at business cycle frequencies due, as shown above, to mismeasurement and to overhead labor.

8.2 ECONOMETRIC ISSUES

The aim of the empirical work in this paper is twofold. First, we estimate the elasticity of measured output to measured hours (β), one of the central parameters in the theoretical analysis summarized in Figure 8.1. Second, we develop an empirical counterpart to the theoretical analysis. Using actual data on output, hours, and utilization, we show which parameters of unobserved output mismeasurement, labor mismeasurement, or labor fixity are required to eliminate the procyclicality of Solow’s residual. In contrast to the work of Hall

and his followers based solely on annual data, all estimates here are based on quarterly data, both for the nonfarm private economy and for the manufacturing sector, using BLS data on output, hours, capital stock, and labor's share.¹⁸

Specification

The use of quarterly data allows us to revive familiar dynamic issues that were much discussed in the 1970s (Sims, 1974; Gordon, 1979) but have been neglected by most papers in the recent revival of this topic.¹⁹ In particular, the earlier work concluded from symmetric two-sided tests that hours respond to changes in output, rather than vice versa, and so hours rather than output should be the dependent variable in productivity regressions. This finding has been ignored in the recent work of Hall and his followers. Here we start with Hall's specifications, then examine the effects of reversing dependent and independent variables, and subsequently provide estimates and an evaluation of each approach.

Hall's empirical work estimates two types of equations, with all variables expressed in first differences. One type (1988) regresses output on hours, which, using the above notation, involves the estimating equation:

$$\Delta x_t = \beta \Delta h_t + \tau + u_t^x. \quad (13)$$

Here τ is the productivity trend, which was assumed to be zero in the theoretical analysis above. The second type of equation (1990a, 1990b) regresses the Solow residual on output, as in:

$$\begin{aligned} \Delta m_t &= \lambda \Delta x_t + \tau + u_t^s, \quad \text{where } \Delta m_t \text{ is computed as:} \\ \Delta m_t &= \Delta x_t - \alpha_t \Delta h_t - (1 - \alpha_t) \Delta j_t. \end{aligned} \quad (14)$$

In both (13) and (14) the error term is interpreted as an unobserved productivity shock. The joint dependence of the dependent variable, independent variable, and error term is offered as a justification for the use of instrumental variables. To purge the independent variable of any correlation with the error term, Hall uses three instruments that, he claims, are affected only by demand shocks, and are thus uncorrelated with productivity shocks. These are the change in real military spending, the change in the (nominal) world oil price, and a dummy for the political party of the President.²⁰

¹⁸ Quarterly data on output and hours come from a BLS diskette corresponding to the standard BLS quarterly releases on labor productivity and compensation. Data on capital and labor's share are available annually from the BLS multifactor productivity project and are interpolated to yield quarterly values.

¹⁹ While quarterly data are an improvement on annual data, Sims (1974) argued that errors introduced by temporal aggregation make monthly data superior to quarterly data.

²⁰ In Hall's first published paper on this topic (1986) the empirical results were of the first type, with output regressed on hours, but no instruments were used. See Shea (1991) for a criticism that Hall's military spending variable is of little use, because of its low correlation with output at the industry level, as well as an attempt to create new demand instruments for particular industries.

Abbott, Griliches, and Hausman (1988) have argued that one would expect the OLS estimate of the coefficient in (13) to be an upward biased estimate of the true parameter.²¹ The argument carries over to (14), since a favorable productivity shock to u_t^s will boost output for any given amount of factor input. However, Abbott, Griliches, and Hausman show that the instrumental variable estimate of (13) yields a higher estimate of β than OLS and consider the possibility that the instruments are positively correlated with the disturbance.²²

Detrending

The difficulties raised by unobserved productivity shocks are related to the issue of detrending. In the work of Hall and most of his critics only a single constant is included to represent the productivity trend, as in (13) and (14), with no allowance for changes in the productivity trend. If unobserved productivity shocks occur not for a quarter or two, but rather persist for years, then the failure to allow for changing trends will bias upward the coefficient on output in (14), since the missing trend slowdown variable in a period with slow productivity growth like 1973–9 will be positively correlated with the output variable.

This essay uses two different methods to separate trend from cycle. The first method computes (separately for output, hours, and capital) a log-linear piecewise trend that runs through quarters when the actual unemployment rate was equal to the “natural” unemployment rate, roughly 6 percent.²³ During the 1955–92 sample period there are seven different trends subtracted from all variables, so that in first difference form there are implicitly seven constant terms with values fixed by the growth rates of trends through benchmark quarters. The use of piecewise loglinear detrending implicitly involves the same method of separating trend and cycle as the more formal approach of Blanchard and Quah (1989), and this is to assume that the unemployment rate is stationary in the long run, that output is not, and that demand disturbances can be represented

²¹ Abbott, Griliches, and Hausman argue for (13) that if there is an unobserved demand shock, both output and factor input will increase, leading to an upward biased coefficient. For the case of a productivity shock they show that if the elasticity of demand is greater than unity, the productivity shock will have a positive correlation with changes in the variable factors of production, including h .

²² Abbott, Griliches, and Hausman based their critique on an early version of Hall (1988) in which the single instrument for Δh in (9) was the change in real GNP. Their argument carries through to the three instruments listed above that are used in the published version of Hall (1988) and in the (1990a) and (1990b) papers as well.

²³ The “natural” unemployment rate is the rate which is consistent with steady inflation and is “backed out” of an equation for price change that includes various lags of price change, the deviation of unemployment from the natural rate, and various measures of supply shocks. The method is developed in Gordon (1982) and Gordon-King (1982). The benchmark quarters are 1949:Q1, 1954:Q1, 1957:Q3, 1963:Q3, 1970:Q2, 1974:Q2, 1979:Q3, 1987:Q3, and 1990:Q4. For all detrended variables, the growth rate of the trend after 1990 is taken to be the 1987–90 rate.

by shocks that occur in common to unemployment and to deviations of output from trend.

A special case of this technique is the allowance for a single break in the productivity trend, as in Rotemberg-Summers (1990). Below we show that estimates of the key parameters (β , λ) are little affected by the choice between a single break or multiple breaks, but that the fit of the equations is improved by multiple breaks.

Alternatively we use the Hodrick and Prescott (1981) filter, which allows the trend to move continuously. The main limitation of the Hodrick and Prescott filter is that the user's choice of the smoothness parameter can yield any arbitrary trend series ranging from a single straight line to a trend that is so variable that it precisely mimics the series being detrended. For instance, one can obtain a Great Depression of arbitrarily small size by setting the Hodrick and Prescott smoothness parameter at a sufficiently low value. In the opposite direction one can obtain detrended values that are almost perfectly correlated with those yielded by the piecewise loglinear trends when a sufficiently high value of the smoothness parameter is used. Thus the use of the Hodrick and Prescott filter involves the imposition of a subjective choice, whereas the piecewise trends have the advantage that they are anchored in the behavior of the unemployment rate.²⁴ A further advantage of piecewise trends is that there is one trend per business cycle, thus achieving a clean break between the business cycle frequency represented by deviations from trend and the lower frequency changes in the trends from one business cycle to the next.

The top frame of Figure 8.2 compares the two methods of detrending for output and the bottom frame does the same for hours. The differences can be easily explained – the techniques provide a similar interpretation of relatively short-duration business cycles (1955–61, 1971–8, 1987–92) but differ on the long-duration expansion of the 1960s and slump of 1980–6. The piecewise loglinear technique, using “outside information” that unemployment was persistently low during the 1960s and persistently high during 1980–6, transfers this information to conclude that output was persistently away from trend. The Hodrick and Prescott technique allows an acceleration of the trend in the 1960s

²⁴ Hodrick and Prescott (1981, pp. 5–8) provide a justification of a value for their smoothness parameter of 1600, and this has been used in their subsequent work (e.g., Prescott, 1986) and that of most other Hodrick and Prescott users. Yet this justification is based entirely on a subjective statement: “Our prior view is that a five percent cyclical component is moderately large as is a one-eighth of one percent change in the growth rate in a quarter. This led us to select $\sqrt{\lambda} = 5/(1/8) = 40$ or $\lambda = 1600$ as a value for the smoothing parameter.” A value of 10 eliminates the business cycle, while a value of 100,000 reproduces the piecewise loglinear detrending procedure and a value of infinity yields a single trend. To interpret their “prior,” consider the Great Contraction of 1929–33 (when real GDP fell 34 percent below a 2.5 percent per year loglinear trend extending from 1928 to 1948). We can multiply their example of $5/(1/8)$ by 5, for a cyclical component of 25 percent and a reduction in the growth trend of $5/8$ percent per quarter or 2.5 percent per year; thus in their interpretation the growth component had zero growth between 1929 and 1933 despite continued growth in the working-age population and in the productivity that would have been observed at a constant unemployment rate.

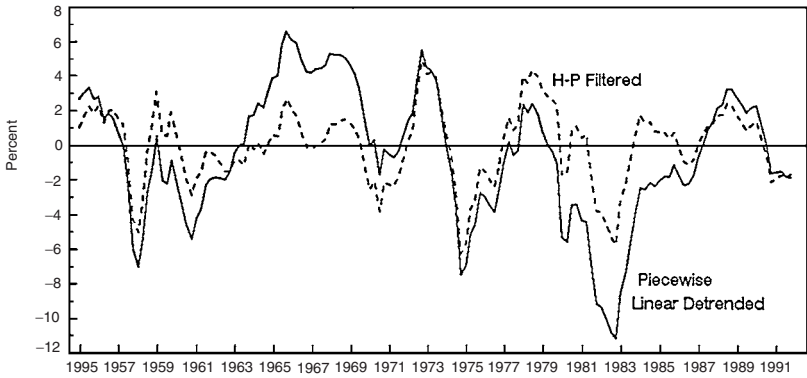


Figure 8.2a. Deviations from Trend of Output, Piecewise Loglinear and Hodrick- Prescott Detrending, Nonfarm Private Economy, 1955:1–1992:1

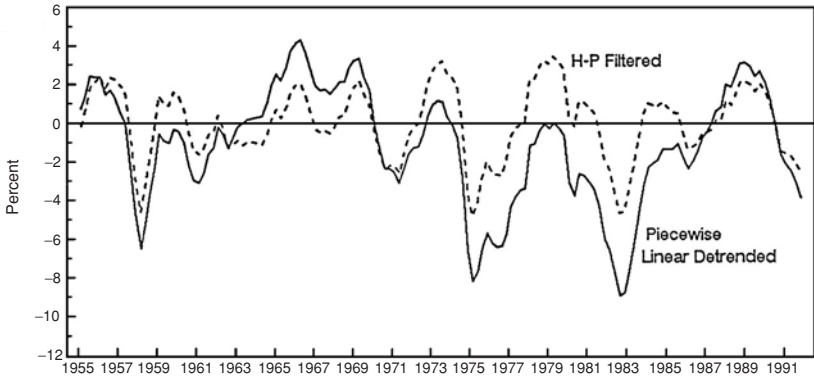


Figure 8.2b. Deviations from Trend of Hours, Piecewise Loglinear and Hodrick- Prescott Detrending, Nonfarm Private Economy, 1955:1–1992:1

and deceleration in the 1980s to absorb much of this cycle.²⁵ More important for this paper, the Hodrick and Prescott technique transfers different amounts of the output and hours deviations from cycle to trend, thus “flattening out” hours and output deviations so that they look the same. Consequently, as we shall see below, the Hodrick and Prescott filter consistently provides an estimate of $\beta(\Delta x/\Delta h)$ that is closer to unity than the piecewise loglinear technique; hence our preference for the latter approach works against our case that procyclical productivity fluctuations are due to mismeasurement of output and inputs.

²⁵ Using the same smoothness parameter, Kydland and Prescott (1990, Chart 2, p. 9) illustrate the log levels of actual and trend real GNP and show how almost all of the boom of the 1960s is interpreted as an acceleration of the trend rather than a deviation of actual above the trend.

Instruments and Reverse Causation

Both methods of detrending eliminate coefficient bias introduced when only a single trend is imposed on the entire postwar period. But we must still deal with the potential problem of coefficient bias caused by unidentified productivity shocks at business-cycle frequencies. One response is to deny that these are important, on the ground that for a productivity shock to account for more than a trivial amount of the sharp decline in output in a typical recession would require an implausible degree of technological regress or “forgetfulness.” While I find this argument convincing, I welcome any remaining bias, because it actually makes the argument of this essay stronger. As we learned from Figure 8.1, any tendency for β to be overestimated makes it harder to accept our basic premise that mismeasurement can explain the procyclicality of MFP. Thus, if we can make the case for mismeasurement with OLS estimates of β , that case becomes even stronger for anyone concerned that β may be upward biased. Finally, if a correctly measured MFP series yields a zero coefficient (λ) on measured output, then the concern about upward bias vanishes. A zero coefficient is not biased away from zero.

In principle one may estimate β either from (13) or from the reciprocal of the coefficient yielded when that regression is run in reverse:

$$\Delta h_t = \gamma \Delta x_t - \tau + u_t^h, \quad (15)$$

where $\gamma = 1/\beta$. While either (13) or (15) may give equivalent answers when responses are instantaneous, they will not yield equal estimates of β in the presence of lags. As Sims (1974) showed in monthly data, the data imply that hours respond to output, rather than vice versa. This is evident from Figure 8.3a, where one can see clearly the lag of hours behind output (in Figures 8.3 and 8.4 the data plotted are four-quarter changes in percentage deviations of log levels from the log-linear piecewise trend). A corollary of lagged hours adjustment is that average labor productivity leads output, as shown in Figure 8.3b. It is well known that the *level* of productivity is related to the first derivative of output, not just the level, and similarly we shall see that the *first difference* of productivity responds to both the first and second derivatives of output.²⁶ This statistical fact buttresses the case for high-frequency adjustment costs as the basic cause of observed quarterly movements in productivity and weakens the case for any explanation that requires the level of output and productivity to move together, such as increasing returns or “thick market externalities.”

Figure 8.4a exhibits the strongly procyclical changes in MFP (Solow’s residual, or Δmt). When MFP is calculated with a series on capital input that exhibits

²⁶ Using the Hodrick and Prescott filter with the standard smoothness parameter (1600), Kydland and Prescott (1990) provide cross correlations of output with current and lagged values of many macro variables in quarterly data over the period 1954–89. They (Table 1, p. 10) confirm our finding that establishment hours lag output and that the Hodrick and Prescott technique provides a series for hours at time $t + 1$ that is almost perfectly correlated (0.92) with output at time t . They also show a strong two-quarter lead for productivity ahead of output.

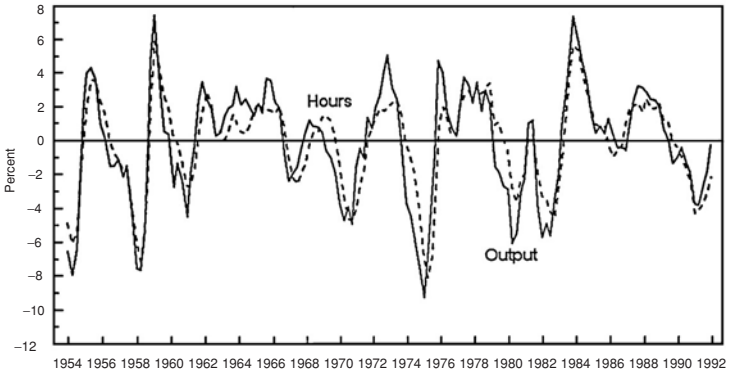


Figure 8.3a. Four-Quarter Change in Deviations from Trend of Output and of Hours, Piecewise Loglinear Detrending, Nonfarm Private Economy, 1955:1–1992:1

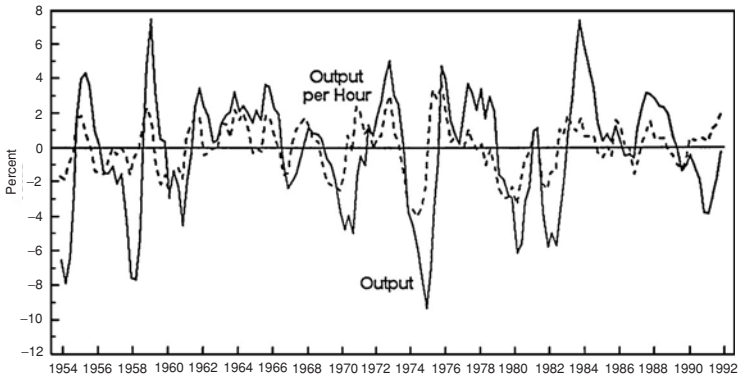


Figure 8.3b. Four-Quarter Change in Deviations from Trend of Output and of Output per Hour, Piecewise Loglinear Detrending, Nonfarm Private Economy, 1955:1–1992:1

little cyclical variation, it is obvious that MFP must be much more procyclical than labor’s average product. This can be easily seen in the extreme case in which detrended measured capital changes are zero ($\Delta j = 0$), since then:

$$\Delta m_t = \Delta x_t - \alpha \Delta h_t = \frac{(\beta - \alpha)}{\beta} \Delta x_t, \text{ implying that}$$

$$\lambda = 1 - \frac{\alpha}{\beta}, \tag{16}$$

which must be less than the coefficient of labor’s average product on output $[1 - (1/\beta)]$ as long as $\alpha < 1$.

An interesting aspect of the basic data is shown in Figure 8.4b, where actual output changes are contrasted with the changes predicted by Hall’s

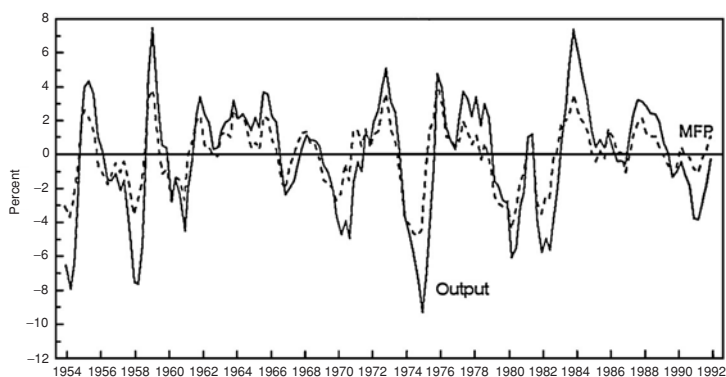


Figure 8.4a. Four-Quarter Change in Deviations from Trend of Output and of MFP, Piecewise Loglinear Detrending, Nonfarm Private Economy, 1955:1–1992:1

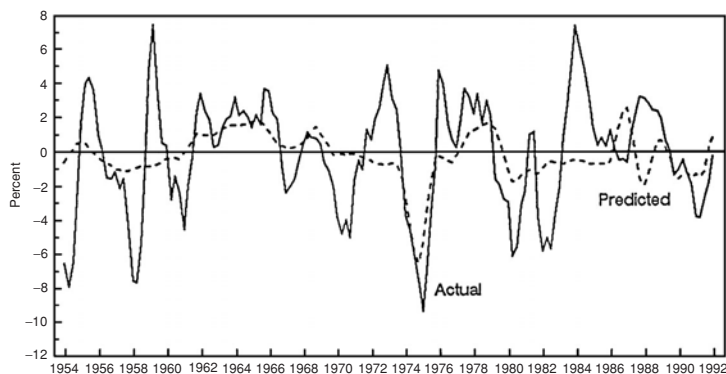


Figure 8.4b. Four-Quarter Change in Deviations from Trend of Output and of Output Predicted by Hall Instruments, Piecewise Loglinear Detrending, Nonfarm Private Economy, 1955:1–1992:1

instruments.²⁷ The chart helps us to understand why a shift from OLS to instrumental variables estimation always leads to an *increase* in the measured β coefficient, as Abbott, Griliches, and Hausman found and as we discover below.²⁸ Simply put, the instruments do a very bad job of tracking shifts in output

²⁷ To adopt Hall's instruments for quarterly data, we first correct his mistake of using the nominal rather than the real oil price, and then use the four-quarter change in the real oil price, the four-quarter change in real defense spending, and a dummy for the political party of the President (this equals unity for the quarters 1961:1–1968:4 and 1977:1–1980:4 and is zero otherwise).

²⁸ A sequel to the Abbott, Griliches, and Hausman paper which confirms their results is Eden and Griliches (1991).

or in hours.²⁹ The \bar{R}^2 in an equation explaining changes in detrended output by a constant and the three instruments is just 0.07, and in an equation explaining changes in detrended hours just 0.05. The oil price change is highly significant with the correct (negative) sign, the political dummy is marginally significant with a large positive coefficient (implying that a Democratic president boosts the growth rate of output by 1.9 percent per annum), while the military variable is wrong-signed and insignificant. The only recession which is decently tracked is 1973–4, an achievement of the oil price instrument. For the other recessions, which are demand phenomena dominated by the yo-yo effect of inventory decumulation on growth, especially 1958–9, 1980–1, and 1982–3, the instruments capture almost none of the variance of output. And in 1986–7 the correlation is negative. Since the instruments “track the interior” of the business cycle, a regression like (14) of MFP change (Figure 8.4a) on the change in output predicted by the instruments (Figure 8.4b) requires a larger coefficient to capture the cyclical effect than would an OLS regression on the actual change in output (the upward bias in the coefficient would be even larger if it were not partially offset by the negative correlation of output and the instruments in 1986–7).³⁰

8.3 ESTIMATION

The SRIRL Parameter

We first provide estimates of the SRIRL parameter β alternatively from a regression of hours on output (as in equation 15) and output on hours (as in equation 13). Eight versions of (15) are shown in Table 8.2, both OLS and IV estimates with four alternative methods of detrending. In all regressions the output variable is entered as the current and three lagged values of the quarterly change. The first pair of columns enter actual first differences with a single constant to control for the trend; the second pair allows two trends; the third pair uses data predetrended by the piecewise loglinear technique, and the fourth pair uses data predetrended by the Hodrick and Prescott filter. The standard errors indicate that allowance for one break in trend is important, but that the fit is improved only marginally by allowing for further breaks as in the third pair. The lower S.E.E. of the Hodrick and Prescott filter versions (columns 7 and 8) results from the tendency of that filter to prefit part of the within-cycle variance

²⁹ Another frequently cited series of papers uses Hall’s instruments to measure external effects on industry productivity (see for instance Caballero-Lyons 1991). The argument of this section suggests that such estimates of external effects are biased upward.

³⁰ Hall defends his use of the oil price variable as a demand shift variable by stating that “changes in factor prices do not shift production functions.” For his statement to be true, MFP would have to be measured net of all inputs which have changing prices, that is, Solow’s residual would have to be measured net of energy and materials inputs, not just net of labor and capital. Hall’s statement is false in the context of all his empirical work, in which measured inputs include only labor and capital, since an increase in oil prices can reduce his measure of Solow’s residual by reducing the input of energy per unit of labor and capital.

Table 8.2. Regressions for First Differences of Hours, Without and with Predetrending, 1955:2–1992:1

	One Trend		Two Trends		Piecewise Loglinear Detrending		HP Filter, Smoothness Parameter = 1600	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Constant Term	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Slowdown (= 0 1955–73; = 1 1974–92)	-1.07**	-1.02	-1.88**	-2.49**	-0.04	0.15	-0.03	0.14
Change in Output	-	-	1.34**	1.54*	-	-	-	-
Change in Output Deviation from Trend	0.85**	0.87**	0.90**	1.13**	-	0.87**	1.05**	1.14**
\bar{R}^2	0.74	0.15	0.77	0.18	0.76	0.18	0.76	0.16
S.E.E.	1.86	3.35	1.75	3.29	1.76	3.25	1.69	3.14
D.-W.	1.50	0.91	1.73	0.95	1.65	0.95	1.83	1.02

Notes. ** and * indicate significance of sum of coefficients at 1 percent and 5 percent, respectively. Coefficients shown are sums of coefficients on lags 0–3 of quarterly log difference in output or output deviation. All quarterly log differences are expressed as annual percentage rates.

Table 8.3. *Regressions for First Differences of Output, with Piecewise Loglinear Predetrending, 1955:2–1992:1*

	Without Leads		With Leads	
	OLS	IV	OLS	IV
Constant Term	(1) 0.02	(2) 0.26	(3) 0.03	(4) 0.34
Change in Hours Deviation				
Current and Lagged (0 to 3)	0.81**	1.50**	0.34**	−0.05
Leads (−3 to −1)	−	−	0.77**	1.78*
Total	0.81**	1.50**	1.11**	1.73**
\bar{R}^2	0.69	0.11	0.72	0.11
S.E.E.	2.67	4.50	2.54	4.54
D.-W.	2.10	1.34	2.22	1.34

Notes. ** and * indicate significance of sum of coefficients at 1 percent and 5 percent, respectively. Coefficients shown are sums of coefficients on lags 0 to +3, −3 to −1, and −3 to +3 of quarterly log difference in the hours deviation. All quarterly log differences are expressed as annual percentage rates. Sample period ends in 1991:Q2 for equations with leads.

of both hours and output, leaving less variance remaining to be explained by the regressions in Table 8.2.

As expected, the instrumental variables versions fit extremely poorly and yield higher coefficients on output than the OLS versions. Finally, the OLS versions yield stable estimates of $\gamma = 1/\beta$, implying β values in the range 1.11–1.18.

In view of the lagged adjustment of hours to output (emphasized by Sims, 1974), we regard Table 8.2 as representing the correct method of estimating β . Nevertheless, it is instructive to see how an investigator could be misled by running regressions of output on hours, as in Hall (1988) and equation (13) above. To show the importance of feedback from output to hours, in Table 8.3 we enter hours in the first two columns with the current and three lagged values only (as in Table 8.2), and in the second pair of columns reestimate the same equation with three leading values added. When leads are excluded, as in column (1) of Table 8.3, the OLS estimate of β is much lower than implied by Table 8.1. Inclusion of leads yields an OLS estimate of β in column (3) of 1.11, very close to estimate of 1.15 implied by column (5) of Table 8.2 that uses the same piecewise loglinear detrending. Once again, the instrumental variables versions fit extremely poorly and yield estimates of β that are far above the OLS estimates. The sum of coefficients on the poorly fitting IV estimate in column (4) of Table 8.3 is 1.73, somewhat below the value of $\beta = 2$ that Hall implicitly assumed when dismissing the importance of measurement errors.

Table 8.4 provides a summary of alternative estimates of β , for both nonfarm business and manufacturing sectors, for both equations (13) and (15), with leads excluded and included, for both the piecewise loglinear and Hodrick and Prescott detrending techniques. Ignoring the third line, which is misspecified

Table 8.4. *Summary of OLS Estimates of the SRIRL Parameter β by Sector, with Hours and Output as Dependent Variables, without and with Leads, 1955:2–1992:1*

	Nonfarm Private Business Sector	Manufacturing Sector
	(1)	(2)
<i>Piecewise Loglinear Detrending</i>		
Hours Regressed on Output		
Lags 0 to 3	1.15	1.24
Leads 3 to 1, Lags 0 to 3	1.30	1.28
Output Regressed on Hours		
Lags 0 to 3	0.81	1.03
Leads 3 to 1, Lags 0 to 3	1.11	1.10
<i>HP Filter, Smoothness = 1600</i>		
Hours Regressed on Output		
Lags 0 to 3	1.11	1.20
Leads 3 to 1, Lags 0 to 3	1.26	1.18
Output Regressed on Hours		
Lags 0 to 3	0.76	0.99
Leads 3 to 1, Lags 0 to 3	1.08	1.02

Note. Sample period ends in 1991:Q2 for equations with leads.

Source. Tables 8.2 and 8.3, and equivalent regressions for manufacturing.

by excluding feedback from output to hours, the top half of the table based on piecewise loglinear detrending exhibits estimates of β that cover a surprisingly narrow range from 1.10 to 1.30. The range in the bottom half (excluding again the third line) is from 1.02 to 1.26; as expected the Hodrick and Prescott filter dampens within-cycle movements of output more than hours and hence reduces within-cycle fluctuations of productivity. All these estimates are below the value of 1.33 called the “empirically relevant” value in the theoretical analysis of Part II; thus that theoretical analysis overstate the amount of mismeasurement that is consistent with an absence of technology shocks. Hall’s dismissal of the mismeasurement approach, implicitly based on β values of 2, seems far off the mark and reflects in large part the poor explanatory power of his instruments and his failure to allow for the lag of hours behind output.

Within-Sample Stability

We now ask whether there is any difference in the cyclical behavior of labor productivity in the two halves of our sample period (1955–73 and 1974–92). We know that the second half was characterized by large oil price shocks, adverse in 1974–5 and 1979–80, and beneficial in 1986. The first half was more clearly dominated by demand shocks. Those who interpret the cyclical behavior of productivity as caused mainly by supply disturbances would expect the cyclical productivity coefficient (β) to be substantially higher in the second half of the

Table 8.5. Summary of OLS Estimates of the SRIRL Parameter β by Sector, with Hours as Dependent Variable, without and with Leads, Alternative Sample Periods, 1955:2–1992:1

	Nonfarm Private Business Sector	Manufacturing Sector
	(1)	(2)
<i>Piecewise Loglinear Detrending</i>		
Lags 0 to 3		
1955:2–1992:1	1.15	1.24
1955:2–1973:4	1.14	1.29
1974:1–1992:1	1.15	1.18
Leads 3 to 1, Lags 0 to 3		
1955:2–1991:2	1.30	1.28
1955:2–1973:4	1.25	1.28
1974:1–1992:1	1.33	1.28
<i>HP Filter, Smoothness = 1600</i>		
Lags 0 to 3		
1955:2–1992:1	1.11	1.20
1955:2–1973:4	1.08	1.25
1974:1–1992:1	1.14	1.13
Leads 3 to 1, Lags 0 to 3		
1955:2–1991:2	1.26	1.18
1955:2–1973:4	1.17	1.20
1974:1–1991:2	1.32	1.18

Source. Regressions in Table 8.2 rerun with alternative lags and sample periods as shown.

sample period.³¹ The interpretation in this paper, based on an absence of shifts in the production function at cyclical frequencies, together with mismeasurement and fixity of labor and capital, would predict no noticeable changes in the estimated β .

Estimates for the full sample period and each half are shown in Table 8.5. In column (1) for the nonfarm business sector the estimated β rises slightly from the first to the last half but falls in column (2) for manufacturing. However, none of these changes are statistically significant. For instance, a Chow test on the shift from 1.17 to 1.32 in column (1), bottom section, yields a $F(8,129)$ ratio of 0.34, compared to the 5 percent critical level of 2.63.

Once hours are chosen as the dependent variable, should the specification include leads? Here the evidence favors excluding the leads. In exclusion tests leading values of the output change variable are jointly insignificant in all the equations for manufacturing, and in all for nonfarm private business that cover the two subsets of the sample period. Leads are significant only for nonfarm private business when a single equation is run across both halves of the sample

³¹ For instance, Finn (1991, p. 26) develops a RBC model with the explicit prediction that “energy price shocks enhance the volatility of Solow residual growth.”

period, presumably indicating a shift in the lag structure over time without a significant change in the sum of coefficients.

The “End-of-Expansion” Effect

In each business cycle expansion there tends to be an initial rapid phase, a point at which the ratio of actual to trend output reaches its peak, and then a slow “plateau” phase through the point at which the actual level of output reaches its peak (this is the business cycle peak as defined in the standard NBER chronology). In (1979) I identified an “end-of-expansion” (EOE) effect in the systematic tendency for firms to increase hours excessively during the plateau phase, so that observed productivity tends to be relatively low during this phase. Then this “overhiring” is corrected after six quarters, so that productivity growth is relatively high (given the normal lagged response of hours to output) in the following two years. This effect was identified in first-difference equations for hours like those estimated in Table 8.2, column (5), with detrending by the piecewise loglinear method.

To examine the robustness of this effect with thirteen years of additional data, I replicated the exact method of the earlier paper. The EOE effect is measured by the coefficient on a single step-like dummy variable that sums to zero. The variable is defined as $+4/6$ for six quarters beginning in the quarter after the peak in detrended output (i.e., covering the plateau phase), as $-4/8$ for the following eight quarters, and as zeros otherwise.³² When added to the equation in Table 8.2, column (5), this single variable reduces the unexplained variance by 12 percent, has a *t* ratio of 4.4, and has a coefficient of 1.4, indicating a tendency for firms to overhire cumulatively 1.4 percent more labor input than needed in the plateau phase, followed by an eight-quarter period in which they shed the unneeded labor. The slow productivity growth observed in 1989–90 and the substantially higher growth observed (together with much publicized “restructuring layoffs”) in 1991–2 are consistent with the continued relevance of the EOE effect.

Which Parameter Values Extinguish the Procyclicality of MFP?

Our theoretical analysis of Figure 8.1 concluded that an observed $\beta = 1.33$ could be explained with any combination of factor fixity and labor mismeasurement adding up to 0.165, for instance zero labor mismeasurement and 0.165

³² The variable is defined as $4/6$ and $4/8$ rather than $1/6$ and $1/8$, because all our log first difference data have been multiplied by 400 to convert them into percentage growth at annual rates. The peak quarters after which the plateau begins are the same as those chosen in (1979) – 1955:Q4, 1959:Q2, 1968:Q3, 1973:Q1, 1978:Q4, plus the addition of 1989:Q1. Following the earlier paper, the phases in the first cycle following 1955:Q4 are reduced from 6 and 8 to 4 and 6 quarters, respectively.

Table 8.6. *Sums of Coefficients (λ) on Quarterly Change in Output Deviation in Regressions Explaining Quarterly Change in Multifactor Productivity Deviation by Sector, with Piecewise Loglinear Predetrending, without and with Alternative Measurement Adjustments, 1955:2–1992:1*

	(1)	(2)	(3)	(4)	(5)
Utilization Multiplied by	0	$1 - \alpha$	$1 - \alpha$	$1 - \alpha$	$1 - \alpha$
Output Mismeasurement	0	0	0	0.10	0.05
Parameter (e^Q)					
Labor Mismeasurement	0	0	0.166	0	0.10
Parameter (e^N)					
Nonfarm Business					
Sum of Coeff. on	0.40	0.12	0.02	0.02	0.01
Output Deviation					
Significance of Sum	0.0E-35	0.5E-02	0.65	0.66	0.82
Manufacturing					
Sum of Coeff. on	0.43	0.12	0.02	0.03	0.02
Output Deviation					
Significance of Sum	0.3E-54	0.2E-03	0.50	0.45	0.66

Notes. Explanatory variables include a constant and lags 0–3 of quarterly log difference in output deviation.

of labor and capital fixed, or completely variable labor and capital with labor mismeasurement of 0.165. Since we have found that the estimated value of β is less than 1.33 in almost every cell of Table 8.5, even less mismeasurement or fixity is required to eliminate procyclical fluctuations in MFP (Δm_t).

While neither the amount of capital and labor fixity nor the amount of mismeasurement can be observed, we can combine the observed procyclicality of measured MFP with alternative assumptions to bracket the required amount of mismeasurement and/or fixity. Our technique is to begin by assuming that capital and labor are entirely variable, and that measured MFP cyclicity combines capital mismeasurement with labor and/or output mismeasurement. With no overhead capital, it follows that true capital input is totally variable and moves in proportion with output. Accordingly, we correct measured changes in capital input for changes in utilization, using the Federal Reserve Board index of capacity utilization. Then we experiment to find values of the other unobserved mismeasurement parameters that will reduce the coefficient on output change (λ) to statistical insignificance in an equation like (14) above that explains cyclical changes in MFP.³³

The results are summarized in Table 8.6, with results for the nonfarm private economy shown above and for manufacturing shown below. When

³³ Unfortunately, the capacity utilization index is available only for manufacturing as well as for mining and utilities, but not for the rest of the nonmanufacturing sector. To create a proxy that reflects the smaller amplitude of cyclical volatility outside of manufacturing, we proxy unobserved aggregate utilization with manufacturing utilization times the estimated elasticity (0.46) of aggregate output changes to manufacturing utilization changes (both detrended).

no adjustments are made for mismeasurement, the respective cyclical coefficients (λ) are large and highly significant, 0.40 and 0.43 for the two sectors, respectively. When the capital stock is adjusted for changes in utilization, the estimated value of λ falls by more than two thirds but is still highly significant. Columns (3) through (5) show the effects on the estimated λ of assuming labor mismeasurement ($e^N = 0.166$), or output mismeasurement ($e^Q = 0.1$), or a combination of both together ($e^N = 0.1$ and $e^Q = 0.05$). All three of these assumed parameter values render λ close to zero and statistically insignificant in both the nonfarm private sector and in manufacturing.

How plausible are these parameters? We earlier interpreted the much-cited results of Fay and Medoff (1985) as implying that $e^Q = 0.1$. More recent evidence by Shea (1990) indicates that accident rates are procyclical. He shows that this can be interpreted to imply either that labor effort is procyclical or that output is mismeasured through the omission of investment-type activities in recessions on which the risk of accidents is lower. Shea shows that the introduction of accident rates can explain 26 percent of the procyclicality of Solow's residual in manufacturing (1990, p. 23). Since the procyclicality coefficient for manufacturing in Table 8.6, column (1) is 0.43, explaining 26 percent of this would yield a contribution of 0.11, almost identical to the contributions of the parameter combinations in Table 8.6, cols. (3) through (5).

As shown in the theoretical analysis, labor fixity is observationally equivalent to labor measurement error. Both taken separately cause measured labor input to fluctuate less than output and thus contribute to the observed procyclicality of labor productivity and of MFP. An alternative interpretation of column (3) in Table 8.6 is that the procyclicality of MFP can be extinguished with no measurement error in output and labor input, but with some fraction of labor input fixed and the remaining fraction variable. With strict capital-labor complementarity ($v^K = v^N$ and $\sigma = 1$), the same fraction of capital input would be fixed as well under this interpretation. The required overhead (i.e., fixity) fraction to eliminate MFP procyclicality is 0.375 with no output measurement error and 0.22 with an output measurement error of $e^Q = 0.05$.³⁴ An even smaller fraction of overhead labor is required if we allow drop the assumption of strict capital-labor complementarity and allow the share of overhead capital to be smaller than the share of overhead labor.

These results, like all those reported in Table 8.6, are based on piecewise linear detrending. Even smaller amounts of mismeasurement are required with Hodrick-Prescott detrending. This relationship occurs, as we noted in commenting on Tables 8.4 and 8.5, because Hodrick and Prescott detrending tends to adjust intracycle movements in output and hours by different amounts, thus

³⁴ Given the estimates presented in Table 8.6, a general formula for the parameter values needed to extinguish procyclicality is:

$$0 = 0.12 - 0.6(e^N - (1 - v^N)) - e^Q + 0.28(1 - v^K).$$

With strict capital-labor complementarity, this is solved for $v^K = v^N$.

Table 8.7. *Coefficients on Quarterly Change in Output Deviation, in Equation Explaining Quarterly Change in MFP, Adjusted as in Table 8.6, column (5), 1955:2–1992:1*

	Nonfarm Private Business Sector	Manufacturing Sector
	(1)	(2)
Coefficient and [t ratio] on Lag		
0	0.348 [10.61]	0.203 [8.02]
1	−0.203 [−5.80]	−0.093 [−3.28]
2	−0.052 [−1.48]	−0.051 [−1.80]
3	−0.082 [−2.54]	−0.043 [−1.73]
Sum	0.010 [0.23]	0.015 [0.44]

Source. Quarterly change in multifactor productivity (Δm_t) is adjusted by the parameter values shown in Table 8.6, column 5.

generating smaller intracycle procyclicality in labor productivity and MFP that require an explanation.

High-Frequency Movements in MFP

Above we noted (in discussing Figures 8.3b and 8.4a) that the level of productivity is related to the change in output, and the change in productivity is related to the second derivative of output. This phenomenon comes out clearly in our econometric results. Even though the equations in columns (3) through (5) of Table 8.6 yield an insignificant *sum* of current and lagged coefficients on output, the individual coefficients are highly significant. As an example, the individual coefficients for the particular parameter choices of Table 8.6, column (5), are recorded separately in Table 8.7. We interpret this result as showing that a demand shock is accompanied by faster response of output than of hours, leading to a transitory positive response in MFP that is completely reversed by the end of the third quarter, eliminating the cyclical correlation in less than one third of the average duration of a business cycle phase.³⁵ This “acceleration” effect is consistent with the hypothesis of costs of adjustment in labor input, but not with a procyclical “level” effect that lasts for the full extent of the business cycle, as required by Hall’s market power explanation, by the real business cycle theory, and by theories of “thick market” externalities.

8.4 CONCLUSION

This essay distinguishes among three different frequency distributions of changes in labor productivity and multifactor productivity (MFP). At low

³⁵ There were seven complete peak-to-peak business cycles between 1953:2 and 1990:3, for an average duration of 21 quarters per cycle, or an average of 10.5 quarters in each cycle of above-average and below-average output growth.

frequencies (longer intervals than the business cycle) productivity grows at variable rates, not a single steady trend, and the most important aspect of this variability has been the post-1973 productivity growth slowdown that has now lasted through more than three business cycles. The secular or low frequency component of MFP movements is identified in this paper alternatively through piecewise loglinear detrending, with one loglinear segment per business cycle, or alternatively by the Hodrick and Prescott filter that allows the trend component to vary within individual business cycles. At the other extreme is the high-frequency component of movements in productivity that we capture by allowing the first difference of hours to take three quarters to adjust to changes in output. In between is the true medium-frequency component associated with the business cycle; it lasts longer than three quarters and has a duration equal to the typical length of a business cycle phase. This paper identifies the high-frequency component with costs of adjustment that lead to a lagged reaction of hours to output that is extremely stable throughout the postwar period. The business cycle component is explained by the mismeasurement of capital input by the stock of capital rather than the utilized portion of that stock, together with modest amounts of mismeasurement of output and/or labor.

With allowance for changes in capital utilization, it takes only a 5 percent mismeasured component of output taking the form of investment or maintenance of physical and human capital in recessions, together with only a 10 percent unmeasured variation in labor effort as a percentage of cyclical variations in true labor effort, to extinguish the procyclicality of MFP at the cyclical frequency. These mismeasurement effects are consistent with the evidence of Fay and Medoff (1985) on countercyclical variations in unmeasured investment activities and of Shea on the procyclicality of accident rates.

Alternatively, there may be no mismeasurement at all of output or labor input, while both capital and labor can be divided into a component varying with output and incorporating $5/8$ of input, while a remaining $3/8$ component consists of overhead labor and capital that vary with capacity rather than output. Adding a small 5 percent component of mismeasured output, the required breakdown of labor and capital shifts to $4/5$ variable input and $1/5$ overhead input.

The implications of our analysis are significant: the behavior of output and inputs over the business cycle denies the relevance of procyclical technology shocks at business-cycle frequencies. The technology shocks that provide the *modi vivendi* of RBC models are absent in U.S. data. Further, if productivity does not exhibit procyclical fluctuations, there is no empirical support for the new generation of search models in which “thick markets” boost productivity in booms. And, if we conclude that there are no cyclical movements in MFP after allowing for modest components of mismeasurement and/or overhead inputs, Hall’s attempt to link aggregate MFP cycles to market power becomes a theory unsupported by fact.

If there is no evidence in aggregate time series data in support of market power or increasing returns, what are we to make of the ample evidence in the micro IO literature that firms do set prices and are monopolistic competitors in product markets? There is an old literature dating back to the 1920s concluding

that a company like General Motors sets price to earn a normal profit at a normal level of capacity utilization, that is, its price is rigid in the sense stressed by Rotemberg and Summers.

However, the fact that price fluctuates less than marginal cost over the business cycle has no necessary implications for the short-run response of labor input to changes in the demand for output.

Instead, the major implication of price rigidity is to make output, as well as correctly measured inputs, more variable than they would be otherwise, since price rigidity causes a given fluctuation in nominal income to be accompanied by a greater change in output than if prices were flexible. This paper shows that, once price rigidity translates nominal demand shocks into real demand shocks, procyclical variations in productivity can be entirely explained by the mismeasurement of capital input as a stock rather than as a utilized stock, together with surprisingly small components of mismeasurement of output, and/or mismeasurement of labor effort, and/or overhead components of labor and capital.

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